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SINGAO*: A VERY LARGE TELESCOPE FOR NEUTRINO GAMMA ASTRONOMY AND COSMIC RAYS STUDIES

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Abstract

We discuss the feasibility of a telescope consisting in a sampling array for extensive air showers measure combined with a muon tracking device. The sampling array will extend over a surface of $\geq 10^7\ m^2$ while the muon tracking device will cover $\geq 10^4\ m^2$.

The telescope should be done with resistive plates counters and would become a very powerful device to study high energy neutrinos and gamma rays astronomy as well as cosmic ray physics up to the highest energy ($\geq 10^{19}\ eV$) region.

INTRODUCTION

According to the most popular models the bulk of cosmic rays is accelerated through shock-wave processes in supernova remnants. However this mechanism seems incapable of attaining the highest energies, the efficiency being limited to rigidities not beyond $10^5 GeV$/nucleon. On the other hand the energy spectrum of cosmic rays extends to $\sim 10^{20} eV$, and therefore different processes in other sites have to be taken into account. Fast rotating highly magnetized objects, as isolated neutron stars or close binary systems, could generate eletric field large enough to accelerate charged particles up to about $10^{17} eV$. Neutral radiation that is photons and neutrinos produced in the interacion of high energy charged particles with some target material, could provide direct information on the existence and nature of these discrete sources. Thus γ and ν astronomy are another very important aspect of cosmic rays studies.

The ambitious project of exploring astrophysical point source of very high energy neutrinos may require detectors of such large area ($\geq 10^4 m^2$), that it seems at present extremely difficult to have them placed in an underground laboratory.

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On the other hand a surface experiment to search for such point sources must distinguish between upgoing muons produced in the interaction of the neutrinos with the terrestrial crust and downgoing atmospheric muons of much more intense flux.

In this document we discuss the feasibility of a very large area telescope dedicated to high energy neutrino and gamma rays astronomy as well as to the study of the cosmic rays spectrum in the energy range $10^{14} \div 10^{20} eV$. This telescope should be built with an array of resistive plate counters (RPC). The possibility of using a combination of streamer tubes and RPC counters for cosmic rays studies has been evisaged in ref. 1. A detailed description of the characteristics of this technique is given in [2]. The RPC technique allows to detect cherged particles with good time ($\sim 1 \div 2\, ns$) and space ($\sim 3\, cm$) resolution covering large areas at low price; it is therefore expecially suitable to built an array of counters which samples the extensive air showers (EAS). Moreover the RPC's allow the construction of a muon tracking decive capable to measure the muon multiplicity with great angular accuracy, and to distinguish between upgoing and dowgoing muons by means of the time of flight (TOF) technique.

Whith such a detector built in Italy will be possible a simultaneous observation of a very high energy γ-rays point sources located in the northern celestial emisphere and the very high energy ν-sources of the southern emisphere.

This document is organized as follows:

A short review of the physical items that can be studied with such a telescope is presented in section I.

The main features of the apparatus are described in section II.

1. GAMMA AND NEUTRINO ASTRONOMY, COSMIC RAYS PHYSICS

1.a Gamma astronomy

Recently the observation of extensive air showers (E $\geq 10^{14}\, eV$) from point sources has been reported by independent observers[3]. The first reported[4] point source of EAS was the now well extablished Cygnus-X3, other reported sources are Vela X-1, LMC X-4 and Hercules X-1. The detection of several other objects has been claimed in the TeV range with Cerenkov detectors. All these sources are also periodic emitters of X-ray radiation, and are interpreted as a binary system composed of a compact object (a neutron star) in orbit with a normal star.

Given our present knowledge of particle physics these air showers must be initiated by γ rays. In fact charged particles are disordered by galactic magnetic field and even extremely energetic neutrons will decay before reaching the earth.

Many models[5],[3] for the UHE photon emission have been proposed which differ in what concerns the nature of the primary beam, the acceleration and radiation mechanisms. The more efficient mechanism to generate UHE gamma rays ($\geq 10^{14}\, eV$) takes into account an hadronic beam interacting with some target material; in fact radiative emission from accelerated electrons is rather unlikely since the increasing energy loss rate by synchrotron emission and inverse Compton scattering should prevent the electrons to reach energies above $10^{15}\, eV$. Protons (or ions) accelerated by the compact star by means of a still unclear mechanism interact with the companion or the surrounding gas to produce a cascade of secondaries. Gamma rays will be produced from π^0 decay and neutrinos from $\pi \rightarrow \mu\nu$ decay. Therefore it is possible to estimate from a measured flux of high energy photons, the expected flux of neutrinos. These neutrinos will be detected through the charged current interactions occurring in the rock below the telescope giving rise to a detected muon.

A summary of the average measured flux from the best observed source Cygnus X-3 is reported in Fig.1. An average of the data, can be represented[6] for ($E_\gamma \geq 0.1\, TeV$) with the simple formula

$$F(\geq E) \simeq \frac{3 \times 10^{-11}}{E(TeV)} cm^{-2} s^{-1} \qquad (1)$$

corresponding to $10^4 events/(year 10^5\, m^2)$ above a threshold energy of 100 TeV. This is an average flux. The most important feature is that the signal has the same periodicity of the X-ray flux with a 4.8 h period that is associated with the orbital motion. The emission of UHE photon is however present only during a small fraction of order $\sim 10^{-2}$ of a period being concentrated in narrow phase intervals.

Cygnus X-3 is anything but a steady source, displaying even in the UHE range a remarkable variability. The phase ϕ of the emission moved during the years from $\phi \sim 0.1 \div 0.2$ to $\phi \sim 0.6 \div 0.7$ [$\phi = 0$ corresponds to the x-ray eclipse]. Data taken in different years exhibit considerable scatter in the measured fluxes. In addition to the long term observations, episodes of enhanced emission have been reported, sometimes correlated to giant radio flares.

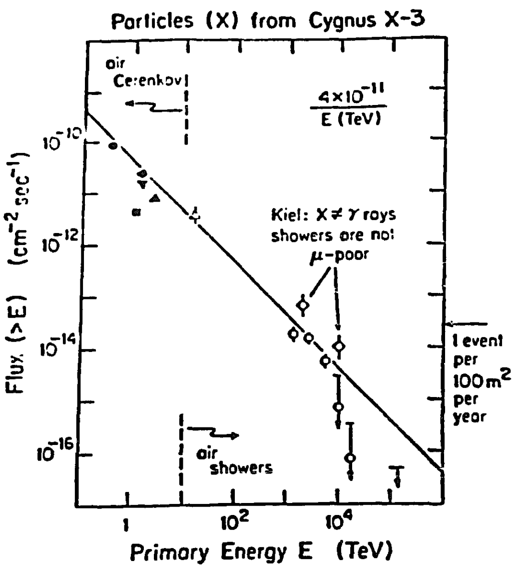

FIGURE 1

Measured flux from Cygnus X-3.

This complicated phenomenology requires high sensitivity air shower arrays capable to identify a positive eccess from a candidate source without making recourse to its periodic nature. In fact for background rejection the experiments have made use of "phase analysis" exploiting periodicity and small duty cycle of the UHE gamma emission. This is a very disturbing aspect in view of the time variability of the emission phase, of the presence of burst-type activity and since many effect might cause a non-uniform background distribution.

The sensitivity depends on the ratio $A^{1/2}/\delta\theta$ (A = effective area, $\delta\theta$ = angular resolution). An effective area of 10^5 m^2 and an angular resolution better than 1° are needed at PeV energies to achieve in on year of data taking a flux sensitivity of $\sim 4\sigma$ solely from counting rate analisis[7]. A high sensitivity apparatus could investigate the shape of the energy spectrum in the range $10^{15} \div 10^{16}$ eV where an absorption dip is expected due to photon-photon pair production on the microwave photons from the 2.7° black body background. This should be the most striking evidence that the primary are indeed gamma rays, which in questioned as discussed below.

At energies above 10^{16} eV an effective area as large as 10^6 m^2 could detect a statistically significant sample of events (~ 240 ev/yr assuming an E^{-1} behaviour and taking into account an observation time of 6 hours/day) to check the existence of the energy cut-off exhibited by the Haverah Park data (based on 9 events observed in 4 years of data taking), but not present in the Kiel data.

The other main problem concerns the nature of the primary radiation. Primaries are not positively identified as gamma rays, this conclusion being reached by requiring that air showers pointing at discrete sourcers are generated by neutral and stable particles, of low or zero mass to preserve the phase coherence. The main technique to distinguish gamma rays initiated air showers from hadron initiated showers is based on the measurements of the muon content. Only few muons are expected in γ-initiated showers, essentially arising from the decay of $\pi^{\pm}$ produced in photonuclear production processes. All calculations indicate a muon content about a factor of twenty less than that produced in hadronic showers of the same energy as shows in fig.2, taken from ref.[6], where the number of muons in excess of 1 GeV is plotted as a function of the shower size for γ and nucleon initiated showers. This expectation comes from the fact that the typical photonuclear cross sections are $\sim 0.5\%$ of the proton nuclear cross section. Therefore, if the muon content is measured, then a sample can be selected that is rich in candidate gamma rays and a rejection of more than 90% of the background cosmic ray showers could be achieved. That means a further increase of the sensitivity by more than a factor of three.

On the other hand, some of the observations of UHE photon showers has been accompained by the still unexplained phenomenon of a muon multeplicity higher than what is normally expected for a gamma induced shower. It is not easy to assess the statistical significange of these results due to the limited area of the muon detectors ($\leq 100\,m^2$), but this effect could be interpreted as exotic interaction of high energy photons, or with the exotic nature of the shower initiating neutral particle. As an example in Fig.2 is presented the muon signature in a model[6] where the photons become strongly interacting at very high energies.

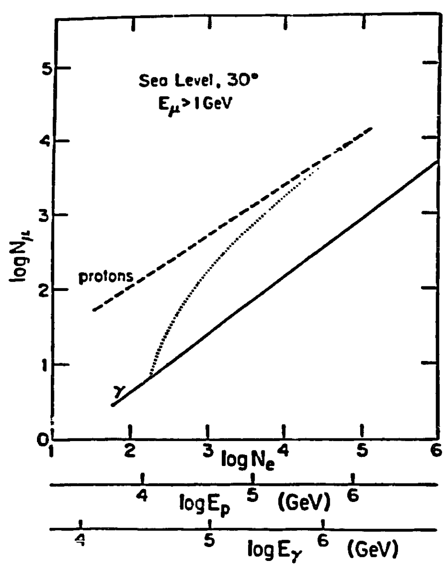

FIGURE 2

Muon content in γ and μ initiated showers vs to the shower size (number of electron N_e).

According to these considerations, the capability of a new generation air shower array to detect simultaneously electrons and muons over the same sensitive area appears mandatory. Muon detectors have to be well shielded against the electronic component and of large area, since the muon density is $< 10\%$ that of electrons. Muon identification should be accomplished by recording the muon track and hence independently measuring the arrival direction of the showeer. No such implementation has been achieved in the existing air shower arrays.

1.b Neutrino Astronomy

As we have discussed in the previours section, we expect a neutrino flux from UHE photon sources. Such fluxes have not been detected up to now, but are expected to be near the level of sensitivity of the largest proposed neutrino detectors. Positive detection of these neutrino sources and study of the correlation between photon and neutrino fluxes will be one of the major area of research in high energy astrophysics.

Several authors[8] have calculated the μ-flux induced by neutrino sources. To estimate the expected signal from a source, we will consider a source located at distance $d = 10\,kpc\,(1\,kpc = 3.085 \times 10^{21}\,cm,$ d is of the order of the galaxy radius), and emitting a power in neutrinos $P_\nu = 10^{38}\,erg/sec$ between 1 GeV and 10^7 GeV, with a power law spectrum $\propto E^{-\alpha}$ *. We obtain an upward muon flux:

$$F_{\alpha=2}(\geq 2\,GeV) \simeq 2.4 \times 10^{-15} \left(\frac{P_\nu}{10^{38}\,erg/sec}\right) \left(\frac{10\,kpc}{d}\right)^2 cm^{-2}\,s^{-1} \qquad (2)$$

or $F \simeq 10\,events/(year\;10^4\,m^2)$.

For steeper spectra, the same power in neutrino will result in a smaller upward muon flux. For a spectra $\propto E^{-2.2}$ the flux is reduced (with the same conditions) to 4 $events/(year\;10^4\,m^2)$, for a spectra $\propto E^{-2.4}$ to 2 $events/(year\;10^4\,m^2)$.

A detector located in Italy would be mainly sensitive to neutrino sources located in the southern celestial emisphere. For neutrino astronomy the observation of a point like source is possible only if it is below the horizon. In Fig.3 we show the average acceptance in a sidereal day for a neutrino source located at celestial declination δ with a detector located at latitude of 42°. In the same figure we show the declination angle of various

* *Cygnus X-3 is located at a distance $d \geq 11$ kpc and emits in high energy photons a power $P_\gamma \sim 10^{37}$ erg/sec. The neutrino flux is expected to be about 10 times stronger because of the longer fraction of the orbit period in which neutrino production is effective.*

expected neutrino sources. As one can see Cygnus X-3 is at the edge of the observation window for neutrino emission, while the LMC X-4, Vela X-1, and Cen X-3 are all well located. Taking into account the measured UHE photon fluxes from these sources, with a conservative estimate we expect a signal of $\simeq 20\, events/year$ from LMC X-4 and $\sim 5\, events/year$ from Vela X-1 for a detector of area $10^4\ m^2$. It should be stressed that these estimates are affected by large uncertainties.

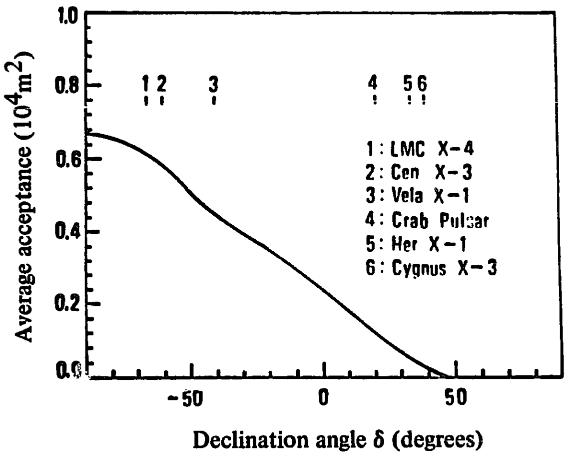

FIGURE 3
Average acceptance of the apparatus as a function of the declination angle. The position of the most important sources is also shown.

The most important physical background is due to the upward muon flux induced by the atmospheric neutrinos. Detailed calculation of the expected fluxes have been performed[9] that are in good agreement with existing data. The upward muon flux for ($E_\mu \geq 2\, GeV$) is weakly depended on the zenith angle, with an average value:

$$\bar{\Phi}(\geq 2\, GeV) \simeq 2.5 \times 10^{-13}\, cm^{-2}\, s^{-1}\, sr^{-1} \quad (3)$$

The expected rate in a flat horizontal detector is:

$$R_{hor}(\geq 2\, GeV) \simeq 2100 \left(\frac{events}{year\ 10^4\, m^2} \right) \quad (4)$$

Lowering the energy threshold the rate increases (same units) to 2400 events for $E_\mu \geq 1\, GeV$ and to 2600 for $E_\mu \geq 0.5\, GeV$.

This background B is weakly depended on the declination angle δ, and is linearly proportional to the solid angle acceptance. For an angular acceptance of one degree we have $B = 0.3\, events/(year\ 10^4\ m^2)$. If the angular acceptance becomes 2 and 5 degrees the background raises to 1.3 and 8 $events/(year\ 10^4\ m^2)$ rispectively.

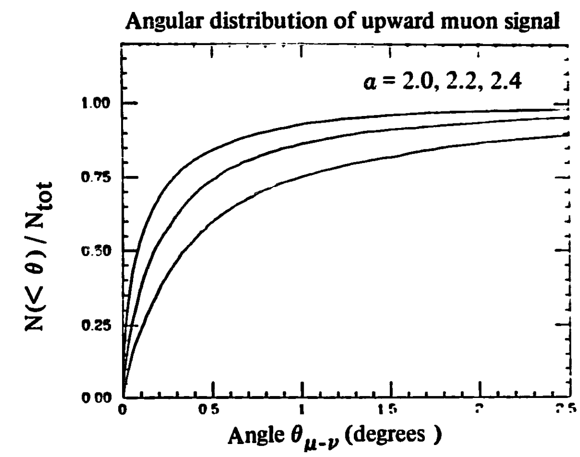

FIGURE 4
Integral angular distributions of the upward muon signal for power law neutrino spectra of for $e^{-\alpha}$.for $\alpha =$ 2.0, 2.2, 2.4, 2.6. These curves are computed neglecting absorption in the earth.

An experimental angular resolution of $\sim 0.5°$ allows to define an acceptance $\sim 1.5°$. Such a value is estimated to be large enough to accept al least 90% of the muons produced by the ν-interactions in the surrounding rock (see fig.4). Therefore we can conclude that with respect to the atmospheric neutrino background a μ-tracking decive with an angular resolution of $\sim 0.5°$ will have a lineary increasing sensitivity to identify neutrino sources up to $\sim 10^4\ m^2$. For larger surfaces the sensitivity will be proportional to the square root of the effective are. Thus a μ-tracking decive with an angular resolution ($\sim 0.5°$) and surface $\geq 10^4\ m^2$ is required to study the high energy neutrino point sources. This large surface implies that the detector must be placed outside of an underground laboratory in conditions of much higher background. The possibility of performing an experiment is such conditions will be discussed in section II.

1.c Cosmic rays at energy above 10^{14} eV

The energy spectra of high energy primary cosmic rays shows to remarkable features more or less well established:

(1) The first is the so called "knee"[10], which is a steepening of the slope occurring at an energy a few times 10^{15} eV. Moreover there is a flatter region from about 10^{14} eV up to the knee so that a "bump" is found between 10^{14} and 10^{15} eV. The exact form of the bump is controversial due to the scatter of the experimental data. On the other hand there is a great deal of astrophysical interest in this region becouse the stepening in the spectrum should reflect a feature in the source (the upper limit in the acceleration process) and/or the failure of the galacting trapping. Magnetic confinement would work efficiently for heavy nuclei with large atomic numbers, therefore the steepening of the spectrum is an evidence that particles above the knee are not confined in the galaxy by its magnetic field and a radical change of the composition across the bend is expected.

Unfortunately air shower and high energy muon detectors (at the surface and undergroud respectively) have produced a very contradictory set of result[11] about the chemical composition at energies $\geq 10^{14}$ eV. The main reason is that many experiments are of low sensitivity, and the mass resolution is very limited. In particular only a few air shower experiments have used decives (of small area) to sample the muon or hadron content besides the electron component. The simultaneous measurement of electron, muon and hadron content, and hadron spectrum at high energies is expected to give important constraints on the nature of the primary. An area of 10^5 m^2 instrumented for this purpose with fine granularity sampling could explore the composition of the primary spectrum beyond 10^{17} eV [$\sim 9 \times 10^4\, ev/year$ in the range $10^{16} \div 10^{17}$ eV, $\sim 700\, ev/year$ between 10^{17} and 10^{18} eV] and eventually detect the spectral features associated with a composition change. In this respect the study of the difference (present in the Akeno data at energies $10^{15} \div 10^{17}$ eV) between that anisotropy of the muon rich and all-particle showers seems very promising in order to derive the relative fraction of heavy nuclei. Furthermore it is possible that the contribution of extragalatic cosmic rays exceeds that of galatic origin somewhere above 10^{17} eV so that the slope of the spectrum may change. Only a few experiments worked in the energy range $10^{16} \div 10^{17}$ eV, data are sparse and affected by severe normalisation problems so that no convincing structure has been yet reported.

(2) A fine structure in the energy spectrum of the ultra high energy cosmic rays (UHCR) around $\sim 3 \times 10^{19}$ eV could result if they were predominantely of extragalactic origin. As early as 1966 Greisen and Zatepsin and Kuzmin[12] suggested that if the cosmic rays travel through the universe for a long enough time their spectrum should steepen abruptly as a result of the energy degradation from photoproduction off the 2.7° blackbody radiation ("blackbody cut-off"). Since then other calculations[13] have been performed showing the possibility of many complicated features of the UHCR spectrum correlated to the distribution and evolution of the cosmic rays sources in the universe. The results from the six air shower arrays wich have operated at the high energy end of the spectrum show significant discrepancies. The Volcano Ranch, Haverah Park and Sidney experiments indicate a flattering of the UHCR spectrum form a spectral index of 3.0 to abourt 2.3 at 10^{19} eV and continuing beyond the Greisen-Zatepsin cut-off up to $E \sim 2 \times 10^{20}$ eV. This behaviour suggests a local supercluster origin of UHCR, the Virgo cluster 20 Mpc away, being possibly the principal source.

On the other hand the Fly's Eye, Yakutsk and Akeno data suggest a blackbody cut-off at about 6×10^{19} eV. In particular, the Akeno group claims the existence of interesting features in the differential energy spectrum as a dip, a bump and a cut-off in that order as the energy increases from 10^{18} eV to 4×10^{19} eV. These should be the signature of the interaction of ultrahigh energy cosmic rays with the 2.7° background radiation in the case ov very remote sources ($\geq 100\ Mpc$).

Thus the observational picture concerning the existence of the cut-off is confusing. On the other hand the statistical significance of these measurements is rather poo - no events above $4\times10^{19}\ eV$ in the Akeno data against an expectation of 4 (based on the Haverah Park data); 1 event in excess of $5\times10^{19}\ eV$ in the Fly's Eye experiment against an expectation of 7 - and severe uncertainties affect the energy determination.

Likewise many discrepancies exist with respect to the anisotropies measured at energies $\geq 10^{18}\ eV$. A Galactic latitude dependence is suggested by data from the Haverah Park, Yalutsk, Akeno and Chacaltaya experiments, possibly correlated with a galatic origin. The Fly's Eye and Sydney experiments do not observe any significant departure from isotropy.

It therefore appears that at energies above $10^{18}\ eV$ the different measurements concerning the absolute intensity, the shape of the spectrum and the arrival direction of the UHCR are inconsistent with each other. This is clearly the evidence of experimental difficulties as well as poor statistical accuracy [the flux at $10^{19}\ eV$ is 1 event/(year km^2)]. A detection are of 10 km^2 is well suitable for physics in the range $10^{18} \div 10^{19}\ eV$. The important region $10^{19} \div 10^{20}\ eV$ demands an effective area of a few tens of km^2. This area should be instrumented to collect for every event accurate experimental informations in order to improve the estimation of energy. In fact the accuracy of the energy estimate are model dependent and a careful reconstruction of both electron and muon lateral shapes very close to the core could provide important constraints on the model of hadronic interactions.

2. THE APPARATUS

A detailed description of the experimental set up is behind the purpose of the present document. The final optimazation of several parameters of the apparatus depends on the height ($\geq$ 1000 m.a.s.l.) at which it will be placed and on the experimental results obtained with a prototype. We present here a possible scheme of the telescope and we discuss its main characteristics.

The telescope consists of two parts: an array of counters which samples electrons and muons of the EAS within an effective area of $\geq 10^7\ m^2$ and a series of high angular resolution μ-tracking modules covering an area of $\geq 10^4\ m^2$.

2.a The EAS detector

The top view of the array is presented in fig.5. The array surface of $3000\times3000\ m^2$ is sampled with $\sim 10^3$ units. Basically each unit consists of RPC ($1\times 2m^2$). On the top of the unit a layer ($\sim 1\ r.l.$) of lead can be placed. The lead acts as a converter of the γ-rays in the EAS, increases the number of the electrons crossing the detector with an improvement of the angular resolution of the shower direction.

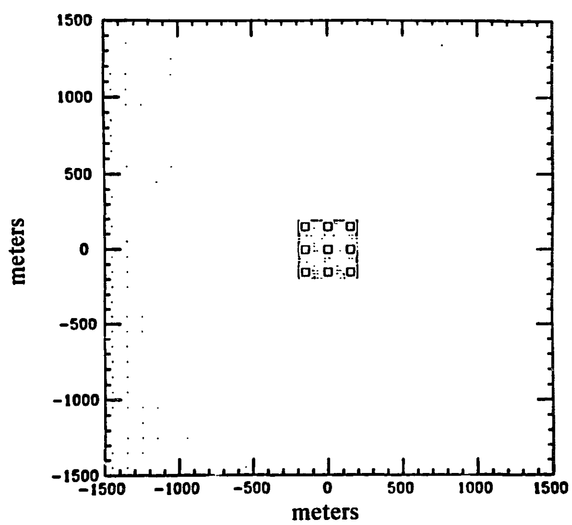

FIGURE 5

Top view of the array; the dots rapresenting the sampling units, the shaded area the μ detectors.

The units form a grid $\sim 100\,m$ spacing over the surface of $\sim 10^7\ m^2$. In the central part $500\times500\ m^2$ the grid becomes $\sim 50\ m$ spacing with an inner core $300\times300\ m^2$ of 10 m spacing. In addition to the described grid used to sample the electron component a grid $\sim 200\ m$ spacing of muon sampling units covering the same effective area will be used. The muon sampling is accomplished by means of three layers of RPC's interleaved with two one meter thick concrete layers. In each RCP plane the position of a particle crossing is measured with an accuracy of $\pm 1.5\,cm$ (the dimension of the pick-up strip); in such a way an angular resolution of $\sim 1.5°$ for a crossing muon is achieved. The area of each unit is 10 m^2.

2.b The muon detector

The second part of the detector consists of modules delicated to μ-tracking and discriminating between upgoing and downgoing muons by the measure of the muon TOF between RPC's.

A schematic view of a module is shown in Fig. 6. It consists of 9 planes of RPC's 40×40 m^2 area interspaced with concrete absorber layers each $\sim 50\ cm$ thick.

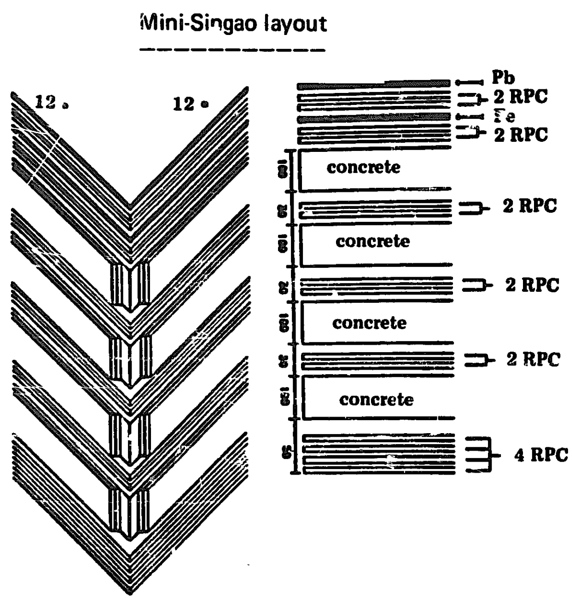

FIGURE 6
Schematic view of a μ-tracking module.

For each RPC plane the measure of one coordinate is performed with 3 cm wide pick-up strips, while the other coordinate is known by the difference of two time measurements taken at the edges of the counter within an accuracy of $\sim 10\ cm$.

The direction of the muons crossing at least 5 meters of concrete ($\bar{E}_\mu \geq 1.5\,GeV$) is measured with an angular resolution $\Delta\theta_\mu \geq 10^{-2}\,rad$, while the time information given by the RPC system allows to identify the upgoing muons out of the much more intense downgoing muon flux.

It has to be remarked that operating such a decive out of an underground laboratory the ratio of the upgoing to the downgoing μ-flux turns out to be $\sim 10^{-10}$. This means that a rejection power better than 10^{10} is needed. The capability of a muon detector of the kind we propose to obtain such a rejection power is discussed in [14] together with a detailed scheme of a possible prototype. At the same time each module will work as a good energy resolution calorimeter to identify high energy hadrons ($\geq 500\,GeV$) near the air shower core.

CONCLUSIONS

The performances of the proposed array (EAS detector and muon detector) with respect to the physics items discussed in section 1. can be summarized in the following points:

(1) The inner part of the telescope ($\sim 2 \times 10^5\,m^2$ of electron sampling and $\sim 10^4\,m^2$ os muon detector) is mainly dedicated to search of γ-ray point sources in the energy range $10^{14} - 10^{16}\,eV$. Assuming a non anomalous μ-production in photon induced showers, this decive operate with a sensitivity as shown in fig.7. If anomalous muon production is present the large (10^4 m^2) μ-tracking area with good angular resolution will permit a detailed study of this exotic phenomenon.

Moreover the muon tracking modules permit to select at trigger level muons coming from definite directions in such a way allowing to follow the path in the sky of candidate sources. These muons can be correlated with the information of the electron component of the shower detected by the upper part of the module and by surrounding counters down to very low electron densities. In such a way the energy threshold of the primary γ-rays can be lowered below $10^{14}\,eV$ approaching the energy region usually studied by the Cerenkov technique.

(2) The surrounding array covering an effective area of

$10^7\,m^2$ will permit the extension of the γ astronomy up to at least $10^{17}\,eV$ [cfr fig.7]. In such a way the whole energy region $10^{13} - 10^{17}\,eV$ will be studied with high accuracy to check candidate sources and identify possible spectral features.

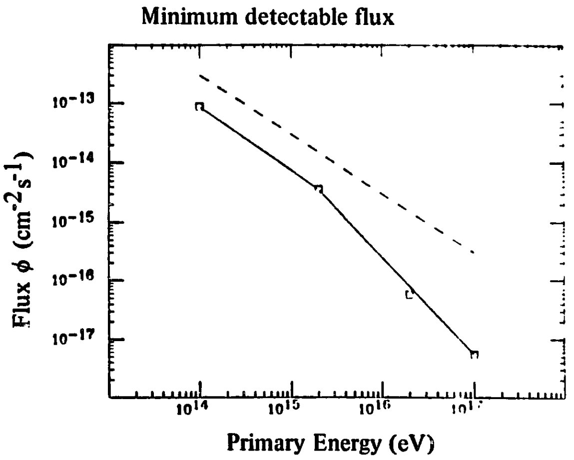

FIGURE 7

Minimum detectable flux from Cygnus X-3 at the 4.5 σ level before phase analysis for one year operation (full line) compared to the measured time averaged flux (dashed curve). An angular resolution of 0.7° at 10^{14} eV and 0.5° for $E \geq 10^{15}\,eV$ has been assumed. A rejection of 90% of hadron initiated showers through use of a muon veto has been taken into account.

(3) The inner part of the planned installation will allow an highly accurate study of the cosmic rays energy spectrum and composition through the "knee" by means of simultaneous measurements of the electron and muon components and of the spectrum of surviving hadrons. The whole array with a total area of $10^7\,m^2$ is adequate to study in detail the energy spectrum and anysotropies up to $\sim 10^{19}\,eV$. For larger energies one may conceive to extend the apparatus with a grid of 500 m up to a few tens of aquare kilometers.

(4) The muon tracking decive is one order of magnitude larger than the present underground telescopes for ν-astronomy (MACRO). Its angular resolution is well suitable to point to candidate neutrino sources as discussed in section 1. Moreover the modular structure allows a continuous expansion.

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